

MAGNETOSPHERIC PHYSICS

Background

From the discussions during the Workshop, it is clear that the space station concept opens the way to an exciting new era of magnetospheric science. The progression of platforms from Spacelab to the LEO Space Station and the GEO Space Station represents a dramatic increase in scientific utility for the key problems of space plasma physics, magnetospheric particle dynamics, and magnetosphere-ionosphere-atmosphere (MIA) coupling.

From our preliminary studies, it appears that the LEO station and the GEO station will benefit greatly from the developments of the Spacelab program. In particular, the opportunity to understand and exploit the full capabilities of scientists-in-orbit in Spacelab should prove to be an important accomplishment. Nevertheless, a number of features of the space station concept provide compelling arguments suggesting that it should be the next step after Spacelab.

Advantages of an STO

For both the LEO and GEO stations, the long-duration observing periods (up to 6 months) should substantially improve prospects for detecting and understanding transient magnetospheric events. The links in a possible chain of cause and effect involved with solar-terrestrial interactions may well be observable only with such an extended mission. In addition, the large payload weight, volume, and power of a space station make it an ideal platform for conducting extensive remote sensing and active perturbation investigations of

the various phenomena involved with the coupling of mass, energy, and momentum in the MIA system. Both the LEO and GEO stations would incorporate the capability to deploy clusters of specialized sensors needed to separate spatial and temporal aspects of the space plasma environment.

It is with GEO, however, that one finds the best opportunity to conduct important new studies relevant to magnetospheric-ionospheric-atmospheric science. As outlined in succeeding paragraphs, the ability to remain nearly fixed on a particular magnetic field line has great importance for a number of outstanding scientific experiments, including the active study of wave-particle interactions, the transmission of charged particle beams through the magnetosphere, and the active radiowave probing of the magnetopause and plasmapause. Since GEO would lie outside the plasmasphere much of the time, it also provides an ideal platform for studying plasmasphere dynamics through active and passive experiments.

Most experiments in magnetospheric physics will require the on-board scientist for their operation. In particular, the so-called "active" experiments in which perturbations are introduced into the magnetosphere require man's pattern recognition and decision-making capability. The scientist will observe the progress of these experiments and modify the operations according to the real-time results.

Program of Investigations

Electric Fields and Currents. Energy and momentum is transferred from the solar wind to the upper atmosphere by means of magnetic field-aligned currents which connect through the resistive high-latitude ionosphere. Both atmospheric Joule heating and a widespread pattern of global electric field

are direct consequences of these currents. Furthermore, there seems to be a direct connection between the field-aligned currents and the acceleration of charged particles producing auroras. This last problem is particularly worthy of study since numerous observations suggest that auroras are an indication of a violation of the basic assumption of classical magnetohydrodynamics; i. e. , that in the low-density plasma of space, the magnetic field lines are equipotentials.

Both the LEO and GEO stations offer dramatic new opportunities to probe the detailed electrical structure of space plasmas with a variety of techniques. Aboard the LEO station, experiments similar to those contemplated with Spacelab would be developed; i. e. , remote imaging of ion tracers, the use of multiple remote probes, and the observation of electron beams. For the GEO station, a far more favorable situation exists since the rapid motion relative to magnetic field lines and the Earth's surface is largely absent. In this situation a charged particle accelerator can be used to full advantage to probe parallel and perpendicular electric fields. Coordinated ground observations, readily obtained for the long-duration GEO station, could accurately pinpoint particle beam atmospheric penetration, permitting study of particle reflections, beam drifts in the presence of perpendicular electric fields, and multi-echo dynamics. Using GEO station remote sensing instrumentation (low-light-level TV, X-ray imagers, and EUV), it may be possible to obtain the same information from the GEO station itself.

Plasmasphere Dynamics. A number of dynamical phenomena are associated with the plasmasphere, including the upward flow of thermoplasma from the ionosphere, the rapid convective drift of plasma in regions poleward

of the plasmopause, the formation of plasmopause red-arcs, and the upwelling of ionospheric plasma above the geomagnetic equator. During magnetic storms, the plasmasphere contracts violently, while afterwards it gradually expands poleward with great upflow of ionospheric plasma.

Much of our present information about the plasmasphere is derived from radio whistlers and in situ spacecraft probes. Neither technique can adequately describe the complex phenomena which seem to occur. Many new plasmasphere observations will be possible using new techniques especially suited to GEO.

From GEO, remote sensing of the plasmasphere will be possible using passive means based on 304A resonance fluorescence of He^+ . Scanning of the plasmopause "limb" should provide a direct view of the spatial and temporal variation of magnetospheric electric fields at the plasmopause; i. e. , information of crucial importance to understanding of substorm phenomena and the general interaction of the plasmasheet and the plasmopause. In addition, fluctuation of 304A EUV intensity within the plasmasphere can be used to deduce for the first time the distribution of thermoplasma along magnetic field lines near the magnetic equatorial plane, a region where strong hot-cold particle coupling is known to occur.

Another technique for probing the plasmopause is the coherent scatter radar, a device which relies upon the scattering properties of plasma density fluctuations viewed perpendicular to $\vec{B}$. Because of the close proximity of the ring current, sufficiently large density fluctuations may exist to permit remote

detection and observation of not only the plasmopause itself, but also irregularity structures internal to the plasmasphere associated with radio whistler ducts.

The same apparatus could also be used in an effort to detect and map the magnetopause throughout various periods of magnetospheric activity. In both cases, synchronous orbit provides an appropriately low density plasma in which radio-wave propagation is possible. Within the plasmasphere, such experiments could prove difficult.

A separate radio technique to probe the plasmasphere can be based on incoherent scatter radar stations at Arecibo, Jicamarca, and Millstone Hill. Using a forward-scatter mode, surface transmissions could be intercepted by an antenna/receiver aboard the GEO station. With appropriate apparatus, measurements of electron density, line-of-sight plasma drift velocity, and plasma temperature could be obtained throughout much of the plasmasphere.

At the plasmopause, both electron and proton precipitation into the upper atmosphere occurs as a consequence of wave-particle couplings. Remote GEO observation of the resulting optical, EUV, and X-ray emissions could provide important new information about the physical processes involved. For example, dynamical motions of the equatorial plasmopause are certain to be present, and a close analogy of the plasmopause-arc situation with auroral observations is present. It is well known that Defense Meteorological Satellite Program and International Satellite for Ionospheric Studies spacecraft observations have opened the way to broad, new understanding of auroral phenomena. Similarly,

GEO observations of plasmopause-arcs (visual, EUV, and X-ray) should dramatically increase our awareness of new processes in this region.

Wave-Particle Coupling Studies. It is well known that wave-particle couplings account for a wide variety of important anomalous plasma processes. Very low frequency (VLF) radio waves, for example, have been shown to resonantly couple with energetic particles of the Earth's trapped radiation belts, leading to particle precipitation and radiation belt depletion. Various other plasma waves of higher frequency are thought to be of great importance to the stability of field-aligned currents, the stability of energetic particle beams, and the establishment of kilovolt electric potentials parallel to the geomagnetic field. Extensive studies of wave-particle coupling will be initiated with Spacelab, but, because of orbital and time requirements, important experiments will inevitably belong to the Space Station era.

The ability to deploy long antennas from LEO will lead to extensive experiments concerning the interaction of extremely low frequency (ELF) and VLF radio waves with trapped radiation belt particles. Because of the great power losses associated with ground-based experiments, space experiments should couple radio waves much more effectively to the trapped particles and provide dramatic new information about the interaction process; GEO, being near the region of maximal interaction, is especially important in this regard.

From GEO, the launching of other, higher frequency waves should prove valuable with respect to studies using artificially generated particles from a

particle accelerator. Destabilization of particles injected into trapped orbits could be accomplished using radio waves with subsequent detection at the foot of the GEO magnetic field line. It is also noted that the operation of a sufficiently strong ELF/VLF transmitter at GEO could lead to a substantial decrease in the local high-energy particle population.

Magnetospheric Disturbances. Substorms involve the rapid release of accumulated magnetic energy in the form of energetic particles and electric currents. Due to their transient character and spatial extension, single spacecraft point measurements of plasma properties within the magnetosphere during a substorm are not sufficient to resolve the basic processes taking place. The GEO station, together with remote probes (small measurement platforms launched as free-flyers or tethered vehicles from the servicing shuttle or space station), can overcome this difficulty, providing new vantage points to selectively study the space-time character of substorms. Observations of plasmopause motion, the structure of the auroral oval visible to the GEO station (presuming a North American parking orbit), and the variations in electric and magnetic fields and particle fluxes at remote probe sites will be difficult to make prior to the GEO station and most probably will be required to resolve the substorm question.

General magnetospheric storms will also be of great interest since there will be numerous opportunities to make observations of many different transient phenomena. The detection of high-energy particles precipitating into the middle-latitude atmosphere could be readily done using a scanning

X-ray detector and imagers working at longer wavelengths. To resolve questions concerning radial variation of quantities, radially tethered remote probes offer an opportunity to separate effects acting over distances of hundreds of kilometers that are obtained through remote scanning. In addition, in situ measurements from remote probes should provide information about structural changes in the magnetosphere associated with substorms.

General magnetospheric storms will provide important targets of opportunity for space station study. The evolution of the ring current, for example, will be an important aspect of magnetospheric storms which can be intensively studied from GEO and a suitable arrangement of remote probes. The LEO station, in contrast, will provide a suitable platform for studies of middle- and low-latitude particle precipitation during magnetic storms.

Relativistic electron precipitation (REP) events have been recently recognized as a feature of the midday auroral zone. Localized in latitude and local time, REP events appear to provide an important loss mechanism for trapped electrons of high energy. The processes responsible for REP's are thought to involve the generation of plasma waves deep in the magnetosphere. However, few details are available, and an extensive LEO and GEO observational program could provide the facts needed to understand the REP phenomenon.